Surveying for Dwarf Galaxies Within the Heart of the Void FN8

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ABSTRACT

The presence or absence of dwarf galaxies with $M_r' > -14$ in low-density volumes correlates with dark matter halos and how they affect galaxy formation: some theories say dwarfs should be present while others say they should not. To help discriminate between theories, we have conducted a red-shifted $H\alpha$ imaging survey for dwarf galaxies with $M_r' > -14$ in the heart of the well-defined void FN8 using the KPNO 4m Mayall telescope and Mosaic Imager. These data have furnished 1187 candidates in a four square degree area.

Subject headings: large scale structure of the universe, galaxies: dwarf, galaxies: luminosity function, galaxies: ISM

1. Introduction

It is well established that on large scales ($\sim 100 Mpc$) galaxies cluster together forming filaments and sheets surrounding seemingly empty voids. This structure reflects the conditions after the big bang and therefore holds keys to understanding how the universe has evolved in the past and will evolve in the future. This is a major reason mapping the large-scale structure of the universe has been a priority of cosmological research.

Of particular interest in cosmology, and many other disciplines, is the nature and role of dark matter. The gravitational influence of dark matter, which led to its discovery, affects the degree of galaxy clustering, meaning the population density of clusters and voids constrain dark matter models. The current understanding of dark matter is that it is made of subatomic particles that do not interact electromagnetically. These are known as Weakly Interacting Massive Particles or WIMPs. Since these particles do not interact through the electromagnetic force they will not emit or absorb light. WIMPs can be sub-categorized based on mass. Hot dark matter particles have a mass of a few $eV$. Warm dark matter has particles with a mass in the $keV$ range. Cold dark matter has masses on the order of $GeV$'s (1). The mass of the particles is directly related to the speed at which they will travel. Hot dark matter having the smallest mass will have the fastest moving particles. Cold dark matter with the largest mass of particles

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will travel the slowest. It has been shown that hot dark matter does not accurately predict the large scale structure we see. Hot dark matter simulations show that galaxies will only be found within very narrow filaments. We see this is not the case. Filaments are much broader and dispersed than what the simulations predict (1). Simulations of both warm and cold dark matter accurately predict the large scale structure that we see. The difference between the two is the number of dwarf galaxies they predict. Warm dark matter predicts fewer dwarf galaxies and cold dark matter predicts more. Within the Local Group the number of dwarf galaxies matches the number predicted by warm dark matter models. Cold dark matter predicts 10 times more dwarf galaxies in the local group. However, dwarf galaxy formation may be suppressed due to ionization and pressure from large galaxies. To be able to truly test the difference between the two models we must look into voids. Warm dark matter suggests there are no dwarf galaxies within the centers of well defined voids. Cold dark matter predicts there should be, though these galaxies should be low luminosity (2). A study of the faint dwarf galaxy population will be a test to the nature of dark matter.

Though there have been many surveys looking at the structure of filaments ((3), (4), (5) and references therein), none have pushed the faintest detection to the $M_r' = -14$ limit where the dwarf galaxies of interest would be found. The SDSS spectroscopic limit of $r > 17.77$ is only able to identify galaxies of $M_r = -14$ out to a $cz$ of 1695 km/sec. The problem being that well defined void centers are found beyond a $cz$ of 4000 km/sec, meaning that these detailed studies have not pushed the lower limit of luminosity to the theoretically interesting boundary.

There have been many studies done which suggest that as galaxy populations get closer to filament and void boundaries the galaxies tend to have later types, and are bluer. Within these populations galaxies with emission are more common than in areas with dense galaxy populations. In low density volumes SDSS shows that 30% show emission with a strength of $H\alpha > 10$ Å equivalent width (6). It is widely held that this same progression should happen within the void volume. This suggests that a population of galaxies within the volume of the void would have a significant proportion of galaxies with $H\alpha$ emission. Due to cosmological red-shift this $H\alpha$ emission will be redshifted depending on distance. By using a set of redshifted $H\alpha$ filters it would be possible to form a photometric method to determine red-shifts, and therefore distances, of these galaxies.

In this paper we present a survey of the galactic void "FN8" chosen from the Foster Nelson catalog from table 2 (4). We have used a set of 3 filters with the $H\alpha$ profile that have been redshifted by different amounts, $H\alpha + 8, H\alpha + 12$, and $H\alpha + 16$, to look for emission galaxies within the heart of the void. In section 2 we present our observation methods. In section 3 we discuss the process of extracting data and choosing candidate objects. Section 4 contains an explanation of our method to determine red-shift from the photometric data. In § 5 we present our conclusion and discuss what else must be done.

2. Observations Method

In February of 2013 we used the KPNO Mayall 4 meter telescope and MOSAIC imager to image the heart of the void we designate as FN8, which coordinates are taken as being the average between the eighth entry of the Foster Nelson catalog (4) and the first entry of the Hoyle and Vogele catalog (7), located at RA = 12h 32m, DEC = +71.3 deg, $cz$ = 4980 km/sec, with diameter = 3660 km/sec. We chose FN8 for being reasonably large, well-defined, having been cataloged by (7) as well as by (4), far enough north to be readily accessible, and at an ideal distance and diameter for the Mosaic Imager filters. We split FN8 into 40 fields, 11 of which we were able to image. These fields pass through the heart of the void. In this paper we present a survey of the galactic void "FN8" chosen from the Foster Nelson catalog from table 2 (4). We have used a set of 3 filters with the $H\alpha$ profile that have been redshifted by different amounts, $H\alpha + 8, H\alpha + 12$, and $H\alpha + 16$, to look for emission galaxies within the heart of the void. In section 2 we present our observation methods. In section 3 we discuss the process of extracting data and choosing candidate objects. Section 4 contains an explanation of our method to determine red-shift from the photometric data. In § 5 we present our conclusion and discuss what else must be done.
has been shown that within dwarf populations there are a number of emission line galaxies (6). These can be used as a means of tracing faint galaxies, such as those expected to be found within a void. At the distance of the heart of the void FN8 the \( H\alpha \) emission will have been red-shifted so that it falls within one or two of the filter band passes. If a galaxy with emission is close to but in front of the void the \( H\alpha \) emission line will be redshifted so that it will appear in the \( H\alpha 8 \) filter. This will cause the object to appear brighter in that filter than the other two. If the object is at the center of the void, the \( H\alpha \) line will be redshifted to the point that it falls within both the \( H\alpha 8 \) and \( H\alpha 12 \) filters, but not the \( H\alpha 16 \), meaning the object will be bright in the \( H\alpha 8 \) and \( H\alpha 12 \) images but faint in the \( H\alpha 16 \) image.

3. Reduction Methods

The data was initially reduced using the KPNO pipeline. The objects of interest are very faint. To help enhance initial detection we summed the \( H\alpha 8 \), \( H\alpha 12 \), and \( H\alpha 16 \) images together then used Source Extractor (8) to make a list of objects. The list usually contained tens of thousands of objects. This list of objects was then used on each of the individual redshifted \( H\alpha \) frames, again using Source Extractor. We were able to determine counts for each object identified from the summed image, on each of the images of the three separate filters.

The next step was to determine the brightness offset of each frame as compared to the others, to make sure that we could accurately compare the objects in each filter for the same section of \( FN8 \) as well as from section to section. To determine the brightness offset we determined a magnitude correction by comparing the magnitude of 4000 objects. These were the 4000 brightest objects that were not saturated on each frame. It is likely that these bright objects are stars, and should therefore have a nearly flat spectrum through these three narrow band filters. If any of the individual objects did have emission, the sample is large enough to diminish its influence allowing us to compare the magnitudes, and adjust so that all of the frames are on an equal brightness.

Once we had counts for the objects identified as candidates, and the frames could be compared, we began a process to reduce the number of potential candidates. We first rejected any object that was flagged from Source Extractor, except those which were flagged because they were possibly galaxies overlapping. Most of these objects are defects in the image. We then rejected all objects that were within the first 150 pixels along the edge of the image. We did this because the objects along the edge didn’t have a full exposure due to the dithering of the images. The next cut was for all objects with an error larger than .2 mag within the \( H\alpha 12 \) filter. Since this is the filter in the center of the sequence, and corresponds to a red-shift in \( H\alpha \) at the middle of the void, we wanted to have a better certainty of detection.

To help us begin to quantify the possible red-shifts we started looking at the ratio of the counts, specifically the counts in \( H\alpha 12/H\alpha 8 \) and \( H\alpha 12/H\alpha 16 \). We chose these ratios so that a galaxy with \( H\alpha \) emission at the heart of the void would have a value greater than one from both ratios, helping to make detection easier. This has the added benefit that stars, whose continuum will be mostly flat through the range of these narrow band filters will have values very near 1 from both ratios. The next step to reduce the number of candidates was to reject 95% of objects that were close to \( H\alpha 12/H\alpha 8 = 1 \) and \( H\alpha 12/H\alpha 16 = 1 \). We did this by forming a multivariate normal distribution. Since these objects have both ratios close to 1, the bulk of these objects will be stars.

To help us further determine objects of interest we created curves for objects of varying emission strengths. These curves were produced by compare the ratios \( H\alpha 12/H\alpha 8 \) and \( H\alpha 12/H\alpha 16 \) as the \( H\alpha \) line was stepped through progressively larger red-shifts see Figure2. Any that had ratio values that would show an emission larger than 10000 FWHM were rejected since it is very unlikely there is an object with such a large equivalent width. We also rejected any candidate with an emission less than 50 FWHM since the bulk of these objects were already rejected based on the multivariate normal distribution as mentioned above. These curves have the added benefit that it will allow us to make an estimate of the expected FWHM for the candidates.

The last step to reduce the number of candidate objects was to go through all of the objects by eye using the software Compare Images developed by J. Moody. In this software a section of the field
The redshifted $\text{H}\alpha$ filters, $\text{H}\alpha + 8$, $\text{H}\alpha + 12$ and $\text{H}\alpha + 16$. The $\text{H}\alpha$ emission line will progress becoming more red-shifted as the object is at greater distances, following Hubble’s law. As the line moves to longer wavelengths it’s transmission through the filters will change. If the object has been redshifted so that its $\text{H}\alpha$ emission line falls near 6660˚A it will have a large impact on the flux through $\text{H}\alpha + 8$ and $\text{H}\alpha + 12$ but have no impact on $\text{H}\alpha + 16$. We can then use this to determine distance to the object.

**Fig. 2.—** The x-axis is the ratio $\text{H}\alpha_{12}/\text{H}\alpha_{8}$. The y-axis is the ratio $\text{H}\alpha_{12}/\text{H}\alpha_{16}$. The dashed oval around the point (1,1) is the area on the graph where stars are likely to be found. To the left of both dashed lines shows the area on the graph that corresponds to the near side of the void. The area in between the two dashed lines corresponds to the area at the center of the void. The area to the right of both dashed lines is the far side of the void. The solid curves show different equivalent widths of the $\text{H}\alpha$ emission line of the object.

4. Redshift, Equivalent Width, and Continuum Determination

As can be seen in Figure 1 the placement of the band passes of the $\text{H}\alpha 8$, $\text{H}\alpha 12$, and $\text{H}\alpha 16$ filters are such that there is a relationship in $\text{H}\alpha_{12}/\text{H}\alpha_{8}$ vs $\text{H}\alpha_{12}/\text{H}\alpha_{16}$ uniquely determined by line equivalent width and redshift value. Figure 2 shows this relationship for emission lines of five equivalent widths as the line is stepped from the front side of the void ($\lambda = 6633\text{Å}$ or $cz = 3220\text{km/sec}$) to the back side ($\lambda = 6712\text{Å}$ or $cz = 6811\text{km/sec}$). This relationship makes it possible to map $\text{H}\alpha_{12}/\text{H}\alpha_{8}$ vs $\text{H}\alpha_{12}/\text{H}\alpha_{16}$ onto both an equivalent width plane and a cz plane.

To do the equivalent width mapping, we first modeled the expected $\text{H}\alpha_{12}/\text{H}\alpha_{8}$ and $\text{H}\alpha_{12}/\text{H}\alpha_{16}$ ratios using the filter tracings from KPNO. We modeled them for discrete values of line equivalent widths in steps of 10˚A from 10 to 200˚A and in steps of 50˚A from 200 to 500˚A. We then made a table of $\text{H}\alpha_{12}/\text{H}\alpha_{8}$ vs $\text{H}\alpha_{12}/\text{H}\alpha_{16}$ for values from 0.95 to 3.0 in each dimension at a resolution of 0.05. Missing entries were filled in by a two-dimensional polynomial fit that assumed the two axes were independent. Finally all table entries were replaced by values from the fit.

The $cz$ mapping was done in a similar manner. The only difference being that the fitting in the $\text{H}\alpha_{12}/\text{H}\alpha_{8}$ direction was done in separate halves for values near $\text{H}\alpha_{12}/\text{H}\alpha_{8} = 1.0$ and $\text{H}\alpha_{12}/\text{H}\alpha_{16} < 1.3$ to avoid a sharp slope in $cz$ values when increasing across the 1.0 value. A sharp slope change is expected since by Figure 1 as the EW approaches zero the upslope and the down slope of the peak get closer together. This
discontinuity is interesting but does not affect the data accuracy.

These two tables were used to assign estimated line equivalent widths and red-shifts to all candidate objects. Of course, we again emphasize that the red-shift estimate assumes the line detected is $H\alpha$ which is certainly not that case for the majority of the objects.

After determining the equivalent width of these candidate objects we were able to determine an estimate for the continuum contribution, and thus determine the r band magnitude for the continuum. The total counts detected through any of the three $H\alpha$ filters can be given by

$$\text{Counts} = C \times (EW_{\text{line}} \times T + EW_{\text{filter}})$$

Where $EW_{\text{line}}$ is the equivalent width of the emission line, T is the transmission percent of the filter at the calculated red shifted wavelength of the $H\alpha$ emission line, C is the contribution from the continuum and $EW_{\text{filter}}$ is the equivalent width of the entire filter. We can then rearrange to solve for the continuum contribution

$$C = \frac{\text{Counts}}{EW_{\text{line}} \times T + EW_{\text{filter}}}$$

After determining the counts it is simple to then translate that into an r magnitude.

5. Conclusion and Discussion

We have presented a method for determining distances to $H\alpha$ emission galaxies within the heart of the void $FN8$ using three redshifted $H\alpha$ filters, $H\alpha8$, $H\alpha12$, and $H\alpha16$. After processing all of the data we have identified 1187 candidate objects within the void. From simulated data we are able to calculate redshift as well as the equivalent width of these objects. Based on calculated redshift of these objects there are 471 objects in the near 3rd of the void, 382 in the central 3rd, and 334 in the far 3rd. The fact that we measure fewer candidates at greater distance is promising. The farther away objects are the less light we receive from them. This means that we would expect to detect fewer galaxies at greater distances, which is precisely what we see.

As we have compiled the data we cannot ignore the fact that we have assumed that the emission line detected is $H\alpha$. This technique will detect any object with a strong emission line that falls within the filter set. While studying the frames it
came to our attention that objects at much larger distances will have the $O[III]$ emission line redshifted into this filter set. We are certain we have detected both distant $O[III]$ emitting galaxies as well as quasars. To be certain of an objects actual distance, it is imperative that the spectrum is taken to identify the true redshift. To this end the candidate objects we have identified comprise a list of potential objects within the void. Due to the very faint nature of the galaxies only a large telescope, such as Gemini or Keck would be able to take the spectra for these objects.

As spectra are taken of these objects, and the redshift is identified, if there are any of these objects that are dwarf galaxies with emission within the heart of the void we will show that the cold dark matter models are correct. On the other hand if we can show that none of the emission line objects we have detected are within the void it shows that warm dark matter models are correct.

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Facilities: KPNO.

REFERENCES


